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A TECHNICAL REVIEW OF DOE ACTIVITIES IN THE EASTERN GAS SHALES

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ABSTRACT

DOE activities in the Eastern Gas Shales are directed at determining the geologic character and magnitude of the Devonian Age Shale gas resource and toward increasing production of natural gas. Geologic evaluations of the collected formation characterization data are essentially complete to determine basin limits and stratigraphic intervals as potential gas sources. With these developments, large areas of the Devonian Shale have evolved as geologic provinces exhibiting certain characteristics that require specific technological developments for extraction.

Concurrently, research has identified the nature of producible gas containment to be the micro- and macro-fractures of the shale formation. Knowledge of these natural fractures, their directionality, and intensity has enabled the development and testing of effective stimulation techniques to connect the gas-bearing conducts to the wellbore. This report describes the rationale supporting the development of provinces within the Eastern gas shales and reviews the results of pilot stimulation tests as an early assessment of the strategy developed to effectively exploit the gas bearing shales.

INTRODUCTION

The Eastern Gas Shales Project (EGSP) is a multidisciplinary research effort directed towards increasing natural gas production from the Devonian Shales of the Appalachian, Illinois, and Michigan Basins of the Eastern United States.

The overall goals of the EGSP are: (1) to develop the technologies that will establish effective and environmentally acceptable means for locating and producing natural gas from Devonian Shales and (2) to reduce the uncertainty surrounding the potential magnitude of reserves so that the private sector will be encouraged to develop the resource on a large scale. Specific objectives of this project are:

- o Development of accurate estimates of gas in place and economically recoverable resources.
- o Development of exploration rationales for the identification of prospects.
- o Development and improvement of cost-effective extraction methods.

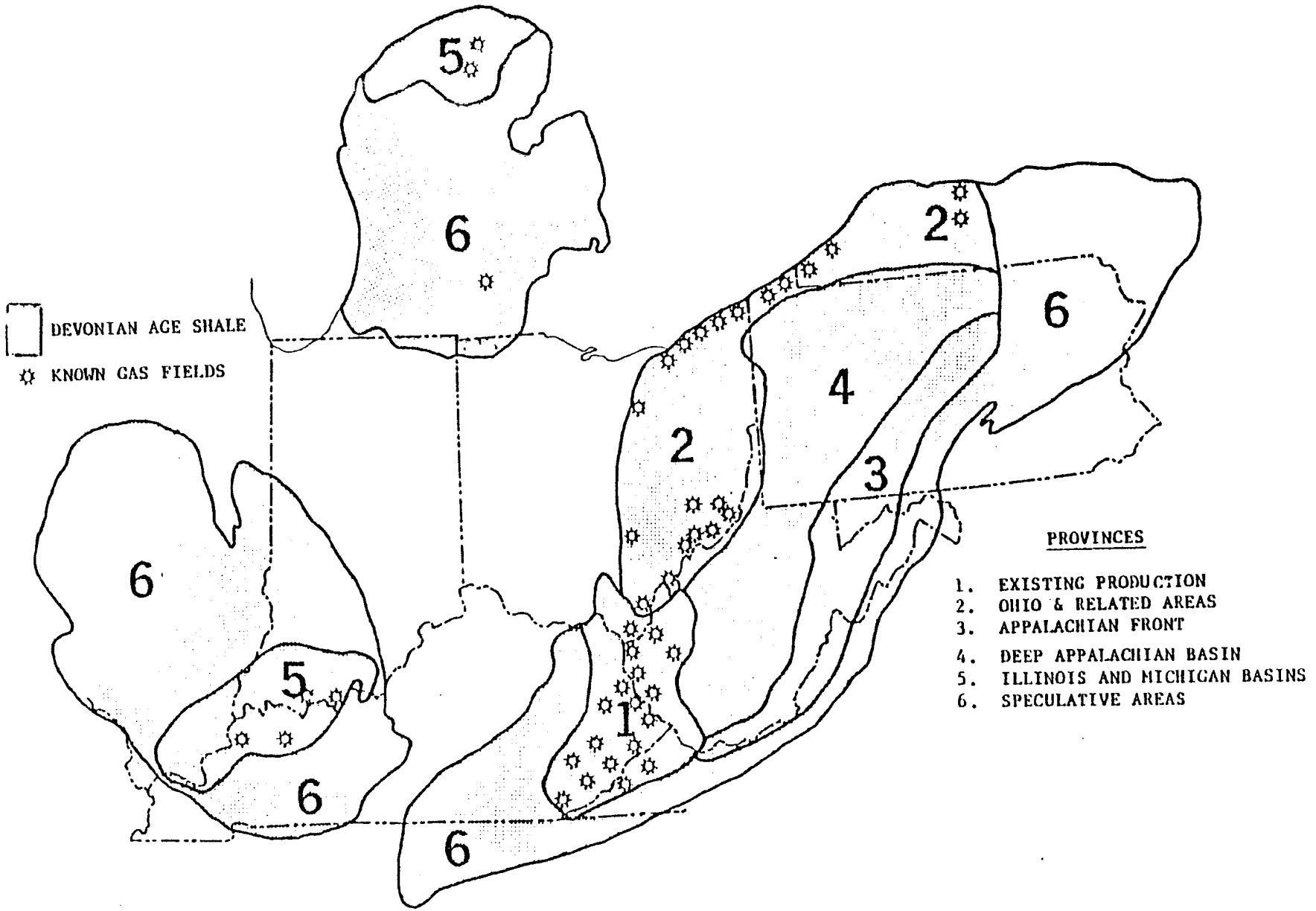
EGSP efforts during the first 4 years of the planned 9-year project have been directed at determining the geologic character and magnitude of the Devonian Shale ggs resource and toward increasing production of natural gas from this resource base. Almost all of the planned formation characterization work required to update the resource knowledge base has been completed. Geological evaluations are essentially complete to ascertain basin limits and stratigraphic targets as potential gas sources. With these developments, large areas of the Devonian Shale have evolved as geologic provinces exhibiting certain characteristics that require particular technological developments for extraction. Accordingly, EGSP activities are planned for each geologic province (Figure 1), namely:

1. Productive areas of Kentucky and West Virginia.
2. Ohio and related areas in New York, Western Pennsylvania, and Northern West Virginia.
3. Appalachian Front in Pennsylvania, Maryland, West Virginia, and Virginia.
4. Deep Appalachian Basin in Pennsylvania and West Virginia.
5. Illinois and Michigan Basins.
6. Speculative areas in all Eastern states.

The EGSP is structured into the following functional categories or program activities:

- o Evaluation.
- o Resource and Site Characterization. .
- o Research, Instrumentation, and Modeling.
- o Production Technology Development. .

EASTERN GAS SHALE PROVINCES AND FIELDS



The first three activities provide for resource data acquisition and the development and testing of techniques for locating probable areas of gas-bearing natural fracture systems and for predicting the probable production from a particular stimulation method in a certain geologic province. The fourth activity is directed at the development and testing of cost-effective methods for extracting gas from the various geologic provinces in the shale. Specific task activities are discussed *in* the following sections.

RESEARCH APPROACH

EVALUATION

The Evaluation activity in the project is designed to integrate facts as they develop; to assess recent technological developments and related industry activities; to ensure compliance with environmental regulations and address site specific environmental problems; to develop a systems model for updating estimates of the potential resource; and to develop and monitor program plans that reflect the integration of the technical, geologic, economic, and other types of data. Tasks and elements that support this activity are listed below:

1. Project Integration:
   - Perform program planning and control.
   - Develop an information management system.
   - Provide engineering analysis.

2. Environmental Problems:
   - Determine baseline conditions.
   - Perform site specific analysis.

3. Non-Technical Constraints:
   - Perform market studies.
   - Assess impact of price on technology.

4. Systems and Economic Evaluations:
   - Develop an integrated systems model.
   - Evaluating shale province economics.

5. Assessment of Resource Potential:
   - Developing gas in-place estimates for provinces.
   - Developing estimates of recoverable gas.

6. Technology Transfer:
   - Developing information file.
   - Prepare and distribute publications.
   - Hosting meetings and workshops.
   - Assessing effectiveness of transfer.

Accomplishments completed include an environmental impact plan for the project, economic analyses of stimulation techniques for the various basins, the establishment of a computerized information retrieval system and pilot resource assessment studies. The technology being developed in the project is being transferred to the private sector through symposia, an open-file library, semi-annual progress reports, newsletters, publications, and presentations.

RESOURCE AND SITE CHARACTERIZATION

This activity of the project is structured to develop the necessary resource data base for characterizing the Devonian Shale provinces and to develop exploration rationales. The information will be used to assess the potential of various resource areas, to guide modeling efforts, and to design stimulation tests. Tasks and elements that support this activity are listed below:

1. Collection of Resource Data:
   - Acquire cores and geophysical loop.
   - Perform basic geologic studies.
   - Perform physical and chemical tests on cores.

2. Development of Exploration Concepts:
   - Perform gas production/geology analyses.
   - Perform lineament/production analyses.
   - Assess geological and geophysical techniques.
   - Assess area1 variation of production with stress.

3. Development of Geological Prospects for Production:
   - Test appropriate exploration rationales.
   - Identify prospects for test wells within *geologic* provinces.

Types of data collected include stratigraphic, structural, sedimentological, physical, and chemical data for identification of gas-bearing fracture systems. Field-work consists of coring and logging to provide data for lab work. Laboratory research includes chemical, physical, elemental, and mineralogical studies to determine the stratigraphic sources of gas and the degree of fracturing in the reservoir. The needed data has been provided through contracts with universities and state geological surveys and the results were compiled and synthesized by the USGS for the various geologic provinces. 'Shale characterization studies are being acquired through contracts to universities, research institutes, and private industry for province R&D efforts to develop and improve methods of locating gas-bearing naturally fractured reservoirs.

RESEARCH, INSTRUMENTATION, AND MODEL DEVELOPMENT

This activity in the project is directed at the development of new diagnostic tools, stimulation approaches, and predictive capability to accurately forecast reservoir performance whenever extraction methods are applied to particular geologic provinces in the Devonian Shale. Meeting these objectives requires basic and applied R&D in the laboratory and the field and the development of models. The models serve to describe the present understanding of the stimulation processes, gas flow from the reservoirs, and economic parameters related to fracturing and production. Tasks and elements that support this activity are described below:

1. Fracture Mechanics Studies:
   - Perform shale/fluid compatability studies.
   - Perform fracture conductivity studies.
   - Update stimulation models for specific provinces.

2. Update Reservoir Production Hodels:
   - Establish petro-physical data base.
   - Update reservoir performance models.
   - Verify reservoir models with performance data.
   - Simulate production for shale provinces.

3. Develop In-Situ Stress Tool:
   - Perform basic design of wireline stress tool.
   - Build and test proto-type tool.

Types of achievements developed to date include the characterization of geologic provinces -for susceptibility to water base fracturing fluids, the development of predictive codes for evaluation of stimulation techniques in specific geologic provinces and the verifications of a production performance model for the shale gas reservoir. The necessary developments were achieved through contracts with universities, DOE's National labs, and private industry. Synthesis of results are the responsibility of the Morgantown Energy Technology Center and its technical support Contractor.

PRODUCTION TECHNOLOGY DEVELOPMENT

This activity in the project is directed at the development of effective stimulation methods for various geologic environments and to test these designs in field applications. The designs tested are conceptual models that have evolved from sequential laboratory and simulation studies. Detailed documentation of field tests under controlled conditions complemented with systematic well testing is conducted through cost-sharing contracts with private industry. Tasks and elements that support this activity are described below:

1. Stimulation Tests:
   - Locate optimum well sites in geologic provinces.
   - Perform site specific stimulation.
   - Evaluate performance with predictive models.

2. Dual Completion Tests:
   - Locate prospects for dual completion wells.
   - Perform site specific stimulations.
   - Evaluate economic aspects.

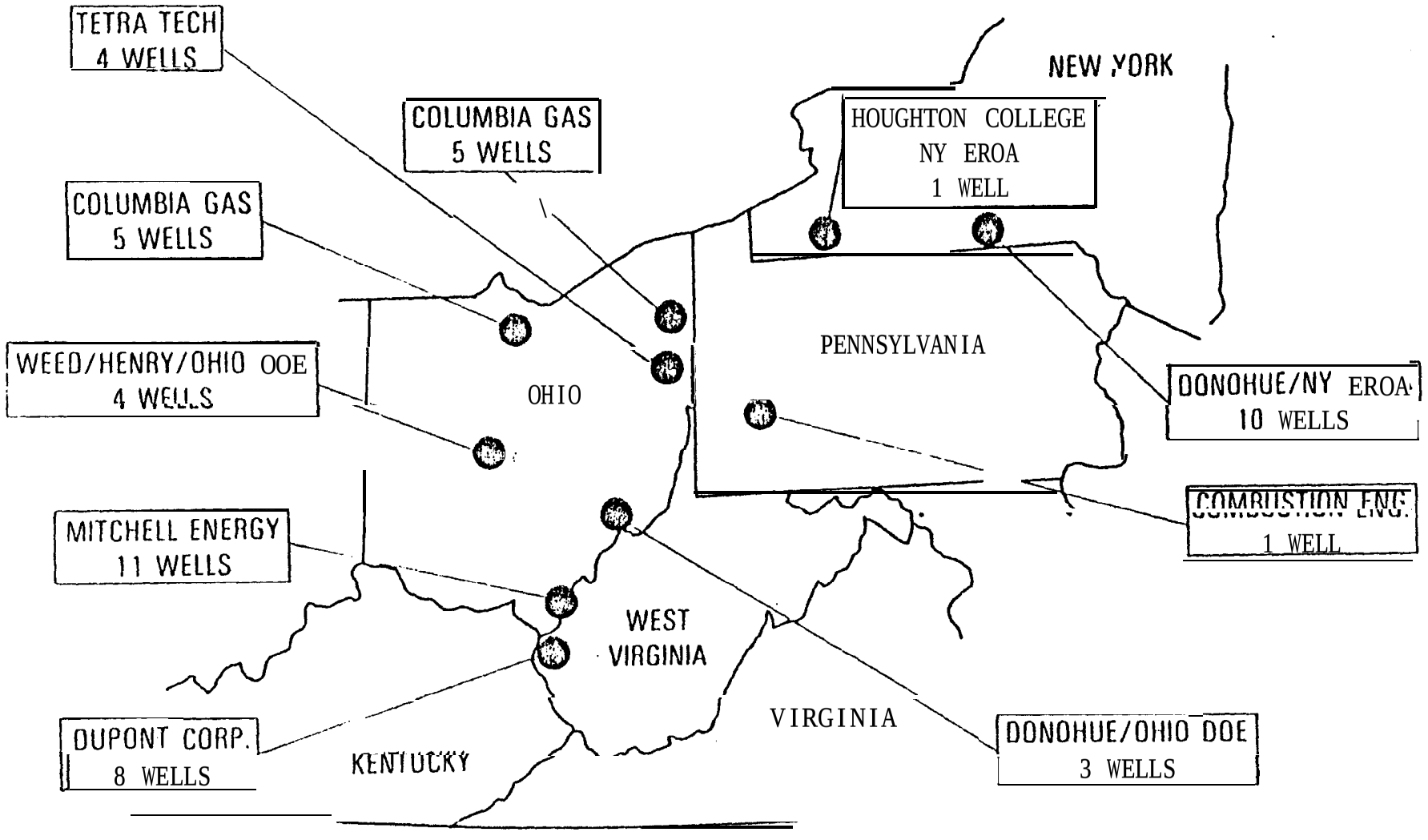
3. Reservoir Performance Analysis:
   - Perform multi-well reservoir interference tests.
   - Determine well performance characteristics.
   - Verify model performance capability.

4. Verify Exploration Rationales:
   - Select sites using specific exploration concept.
   - Collect data from wells for analysis.

5. Test Exploitation Rationales:
   - Select sites in geologic provinces.
   - Stimulate and test wells.
   - 'Evaluate cost-effectiveness of techniques in geologic provinces.

Together with siting wells adjacent to phototraces from aerial photography analyses, both exploration and exploitation testing in geologic provinces are in progress. (Figure 2.) They are:

EASTERN GAS SHALE TEST SITES
FY '79-80



Columbia Gas System -- A total of 10 wells have been drilled in Lorain and Trumbull Counties, Ohio, for production tests of new prospects in gas province 2. Comparative analyses of two stimulation techniques in each area is planned.

Mitchell Energy Corporation -- A total of 11 wells have been drilled in Gallia County, Ohio, in gas province 2 to test and verify a new exploration concept for locating gas-bearing fractured reservoirs. The concept is based on the depositional model for clastic sedimentation wherein natural compaction fractures are found along the flanks of the depositional highs.

Donohue, Anstey and Horrill -- Three wells are planned for Noble County, Ohio, to test the production potential of prospects selected on the basis of seismic velocity lows which are indicative of naturally fractured reservoirs. The concept being evaluated is a new exploration technique applicable to all the geologic provinces in the shale. The project is a cost-sharing venture with Ohio DOE in gas province 2.

Donohue, Anstey and Morrill -- A IO-well project for the Southern Tier Counties of New York is in progress to test the production potential of new prospects based on the exploration concept tested in Ohio. The project is a cost-sharing cooperative venture with NY ERDA in gas province 2. Stimulation techniques selected for testing will be based on site specific geology.

Thurlow, Weed and Associates -- This contract is a 4-well test program to determine the most effective means of stimulating gas production from the shale in the Knox County, Ohio, area of geologic province 2. Support for this test program has been obtained from Ohio DOE.

DuPont Corporation -- An g-well test project in Putnam County, West Virginia, of geologic province 1 is in progress to evaluate the effects of an improved explosive fracturing technique in the peripheral area of established shale production.

Additional requests for proposals are intended to investigate the production potential of areas identified as prospects in geologic provinces 3 and 4.

RESEARCH RESULTS

Observations made to date indicate that gas occurs in natural fracture systems within the shale formation. The fractures serve as reservoirs and also as channels of high permeability for movement of the gas to producing wells. Because the gas production rates associated with conventionally completed wells have been too low to be economically attractive, efforts have been directed toward the development of stimulation and drilling methods to connect more gas-bearing natural and induced fractures to the wellbore. Development of this resource by the private sector has been slow, however, because little is known about the native fracture systems. The high variability in production potential adds to the uncertainty facing poteniial developers. The results of research completed to date in the fourth year of the project has increased the knowledge base upon which some strategy for exploitation can now be formulated. Specific accomplishments achieved in the project are summarized:

- Over 20,000 feet of oriented and non-oriented Devonian Shale core from 40 wells have been recovered for characterization studies. Significant physical, geochemical, and geological relationships have been determined for Devonian Shale samples to ascertain the source bed in stratigraphic intervals. (Figure 3.)

- Geologic studies have resulted in the determination of the cause, occurrence and mode of fracturing in the Devonian Shales, and the delineation of gas-rich zones in the subsurface.

- Field tests' (16) and demonstration projects have shown that advanced stimulation technology (foam, cryogenic, MHF, and chemical explosive fracturing) will improve production more than conventional wellbore explosive stimulation in the gas province associated with historical shale production. (Tables 1 and 2.)

- Several novel exploration techniques for locating Devonian Shale gas reservoirs are being tested and evaluated and look promising.

- Current assessments of total gas-in-place have been calculated to range from 277-903 Tcf. (Figure 4.)

- A mathematical model for gas flow in Devonian Shale has been developed (yet to be verified).

- Foam fracturing for stimulation of Devonian Shale wells has been assessed. Foam fracturing appears to be suitable for shallow, low temperature, and low permeability Devonian Shales. Sand concentrations are currently limited to 1 pound per gallon.

- 'Deviated well technology has been demonstrated but requires replication to determine its full potential.

- An engineering assessment of factors affecting gas production has determined that formation permeability and induced fracture length are most important.

Accordingly, EGSP research has identified the nature of producible gas containment to be the micro- and macro-fractures of the shale formation. Knowledge of these fractures, their directionality, and density has enabled the development and testing of effective techniques to connect the gas-bearing natural fractures to the borehole. Tests of stimulation techniques in light of the geologic environment in the respective gas provinces have permitted the development of a rationale for stimulation strategy. The results of these pilot tests are undergoing systematic evaluation to permit refinement of R&D objectives. Initial economic analysis of Devonian Shale stimulation ventures have been encouraging and indicate that shale gas production should be technically and economically viable in some geologic provinces. (Tables 1 and 2.)

EASTERN GAS SHALE CORE SITES

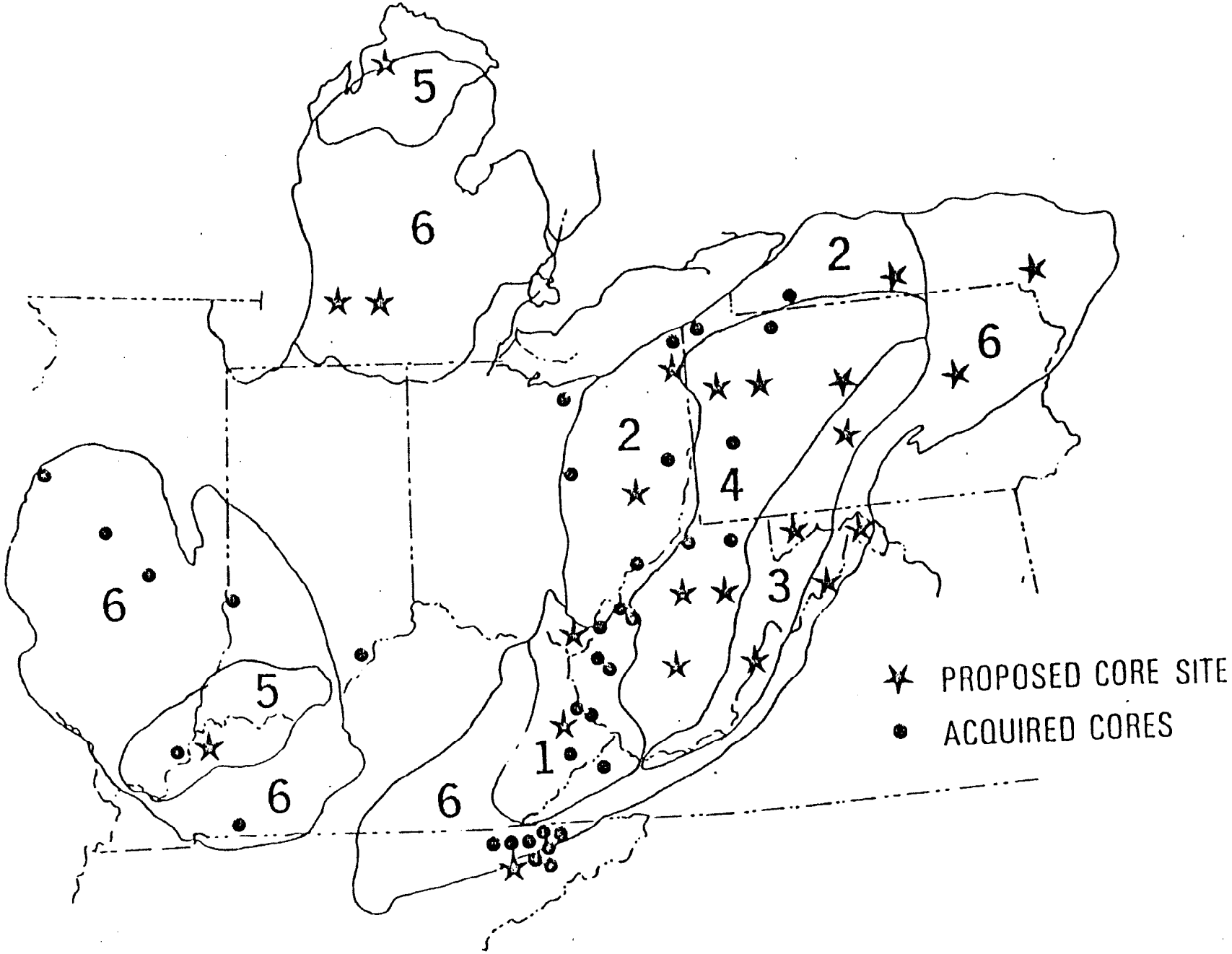


TABLE 1

SUMMARY OF STIMULATION TESTS

COMPLETED:

GAS PROVINCES

No/Average Flow

NO/TYPE	1	2	3	4	5	6
4 MHF	4 (255)	0	0	0	0	0
6 CRYOGENIC	3 (301)	1 (36)	0	2 (21)	0	0
8 FOAM	4 (207)	2 (150)	0	0	2 (283)	0
5 CHEM. EXPLOSIVES	5 (314)	0	0	0	0	0
23	16	3	0	2	2	0

TABLE 1 (Continued)

SCHEDULED:

GAS PROVINCES

NO/TYPE	1	2	3	4	5	6
3 CRYOGENIC	0	3	0	0	0	0
31 FOAM	0	31	0	0	0	0
3 CHEM. EXPLOSIVES	0	3	0	0	0	0
8 SOLID EXPLOSIVES	8	0	0	0	0	0
45	8	37	0	0	0	0

TABLE 2

PILOT TESTS OF STIMULATION TECHNIQUES

IN THE

EASTERN GAS SHALES

GAS PROVINCE NO. 1

Stimulation Type	State	county	Contractor	iaitial Flow (MCFD)	Average Flow (MCFD)
MASSIVE HYDRAULIC	WV	Lincoln	Columbia	322	
FRACTURING	WV	Lincoln	Columbia	38	
	WV	Lincoln	Columbia	145	
	WV	Jackson	Consolidated	173	255
CRYOGENIC FRACTURING	KY	Martin	Columbia	620	
	KY	Martin	Columbia	133	
	VA	Wise	Columbia	150	301
FOAM FRACTURING	KY	Perry	KY/WV	60	
	KY	Perry	KY/WV	337	
	KY	Perry	KY/WV	103	
	WV	Mason	Reel Energy	330	207

TABLE 2 (Continued)

CHEMICAL LIQUID	WV	Lincoln	PTC	260	
EXPLOSIVE FRACTURING	WV	Lincoln	PTC	300	
	WV	Lincoln	PTC	310	
	KY	Pike	PTC	350	
	KY	Pike	PTC	350	314
Ref: State-of-the-Art Technology:		Borehole explosives (80% gelled Nitro)			226
for Gas Province No. 1		Hydraulic fracturing (water)			176

GAS PROVINCE NO. 2

CRYOGEX TC FRACTURING	OH	Trumbull	Columbia	36	36
FOAM FRACTURING	OH			0	
	NY			615	308
Ref: State-of-the-Art Technology: Borehole explosives (80% gel)					120

GAS PROVINCE NO. 4

Stimulation Type	State	county	Contractor	Initial Flow (MCFD)	Average Flow (MCFD)
CRYOGENIC FRACTURING	WV	Monongalia	DOE/METC	12	
	PA	Alleghany	Comb. Engr.	30	21

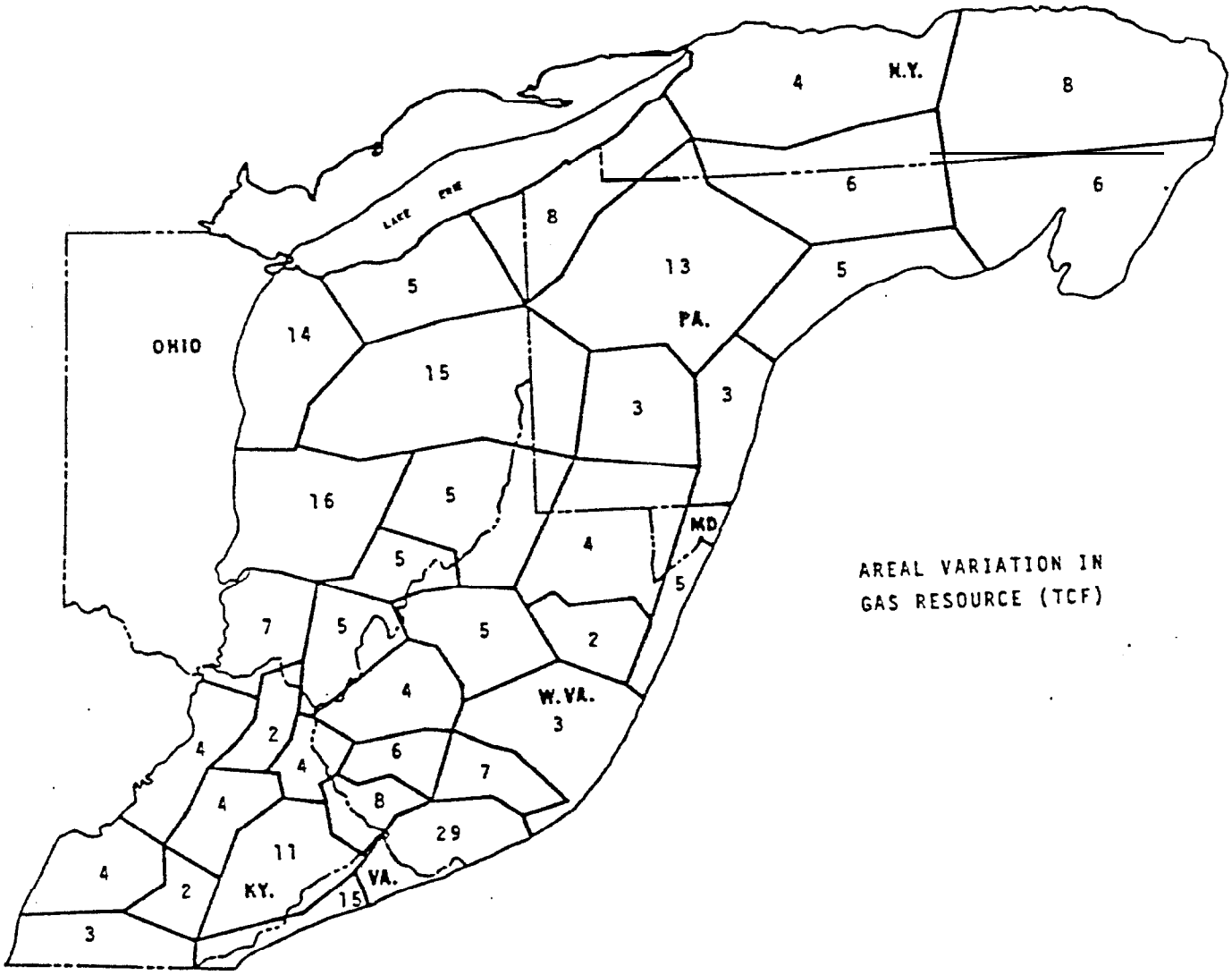
Ref: State-of-the-Art Technology: None.

GAS PROVINCE NO. 5

FOAM FRACTURING	KY	Christian	Orbit	15	
	MI	Ostego	Welch	550	283

Ref: State-of-the-Art Technology: Borehole explosives in KY, limited data, unavailable.
Hydraulic fracturing in MI, limited data, unavailable.

Note: No stimulation activity has occurred in Provinces 3 and 6.



AREAL VARIATION IN
GAS RESOURCE (TCF)

Detailed project plans and milestones for investigation of the defined geologic provinces are illustrated in Figure 5. Project efforts are intended to determine areal extent of potential gas producing regions within the outlined provinces and to quantitatively determine availability so that industrialists in relatively energy intensive activities such as those producing chemical, plastic, rubber, and glass products might be able to plan for an uninterrupted or expanded supply of natural gas.

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GAS
ENHANCED GAS RECOVERY
EASTERN GAS SHALES PROJECT